

Applying Biomimetic Algorithms for Extra-Terrestrial Habitat Generation  
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The objective is to simulate and optimize distributed cooperation among a network of robots tasked with cooperative excavation on an extra-terrestrial surface. Additionally to examine the concept of directed Emergence among a group of limited artificially intelligent agents.

Emergence is the concept of achieving complex results from very simple rules or interactions. For example, in a termite mound each individual termite does not carry a blueprint of how to make their home in a global sense, but their interactions based strictly on local desires create a complex superstructure. Leveraging this Emergence concept applied to a simulation of cooperative agents (robots) will allow an examination of the success of non-directed group strategy achieving specific results. Specifically the simulation will be a testbed to evaluate population based robotic exploration and cooperative strategies while leveraging the evolutionary teamwork approach in the face of uncertainty about the environment and partial loss of sensors. Checking against a cost function and 'social' constraints will optimize cooperation when excavating a simulated tunnel. Agents will act locally with non-local results.

The rules by which the simulated robots interact will be optimized to the simplest possible for the desired result, leveraging Emergence. Sensor malfunction and line of sight issues will be incorporated into the simulation.

This approach falls under "Swarm Robotics", a subset of robot control concerned with finding ways to control large groups of robots. Swarm Robotics often contains biologically inspired approaches, research comes from social insect observation but also data from among groups of herding, schooling, and flocking animals. Biomimetic algorithms applied to manned space exploration is the method under consideration for further study.

# Applying Biomimetic Algorithms for Extra-Terrestrial Habitat Generation

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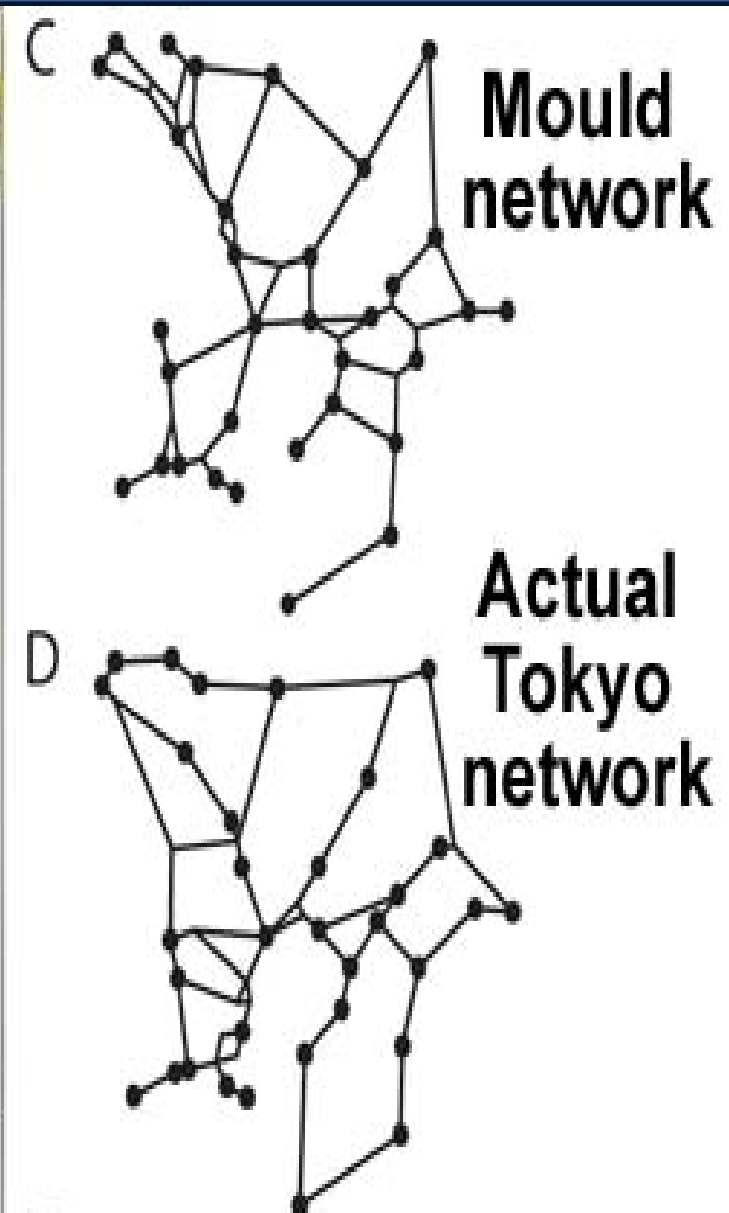
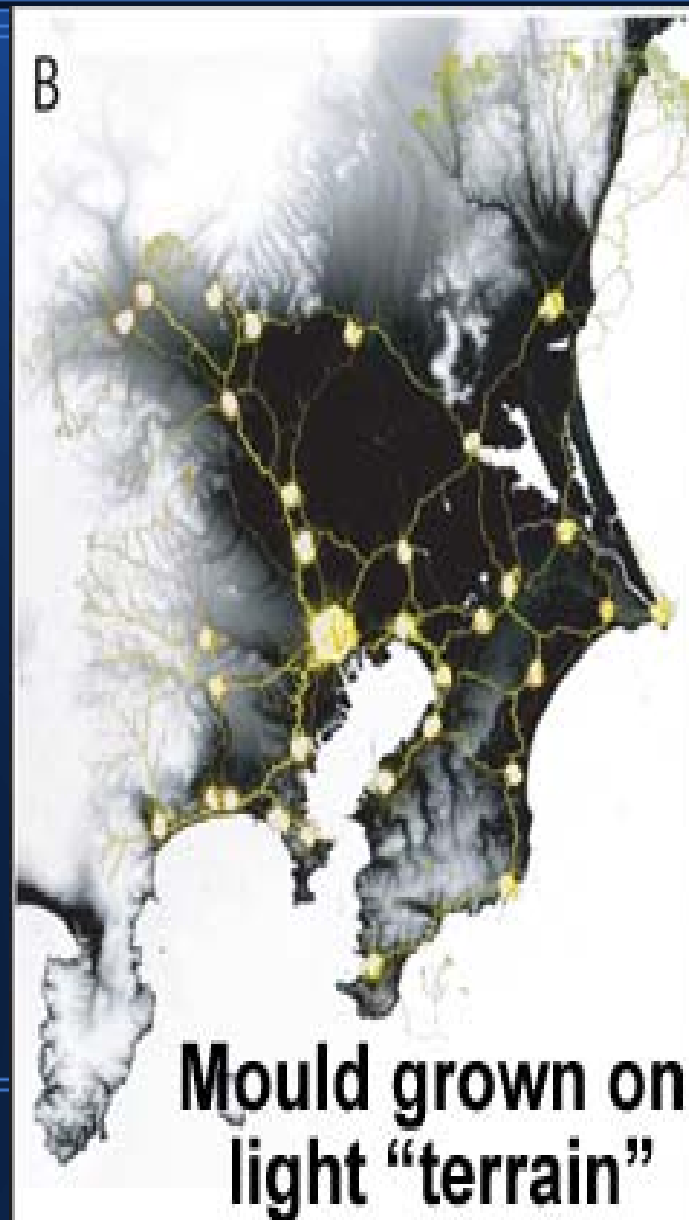
- Biomimetic Algorithms
- Problem Definition
- Approach
- Summary
- References & Further Reading

# Biomimetic

- Biomimetics – the study of structure and function of biological systems as models for the design of materials and machines.
- In reality application is more often biologically “inspired” than true mimicry.
- The natural world is an ever changing system of systems at vastly different scales that effect each other from small to giant ways.
- Taken as a whole, the system can be said to be “self organizing”.

# Biomimetic - Examples

- Communication



# Biomimetic - Examples

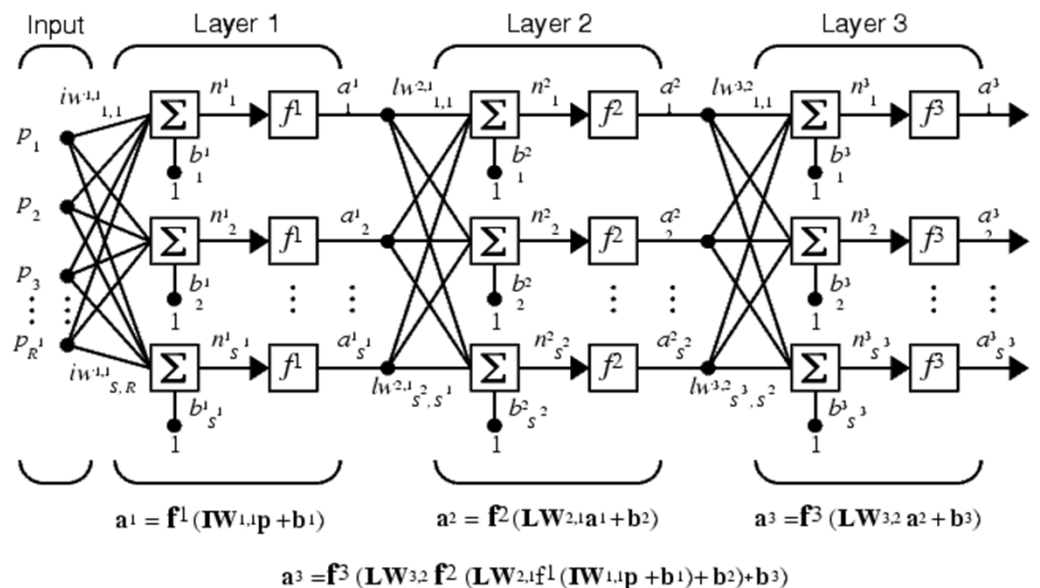
- Art & design





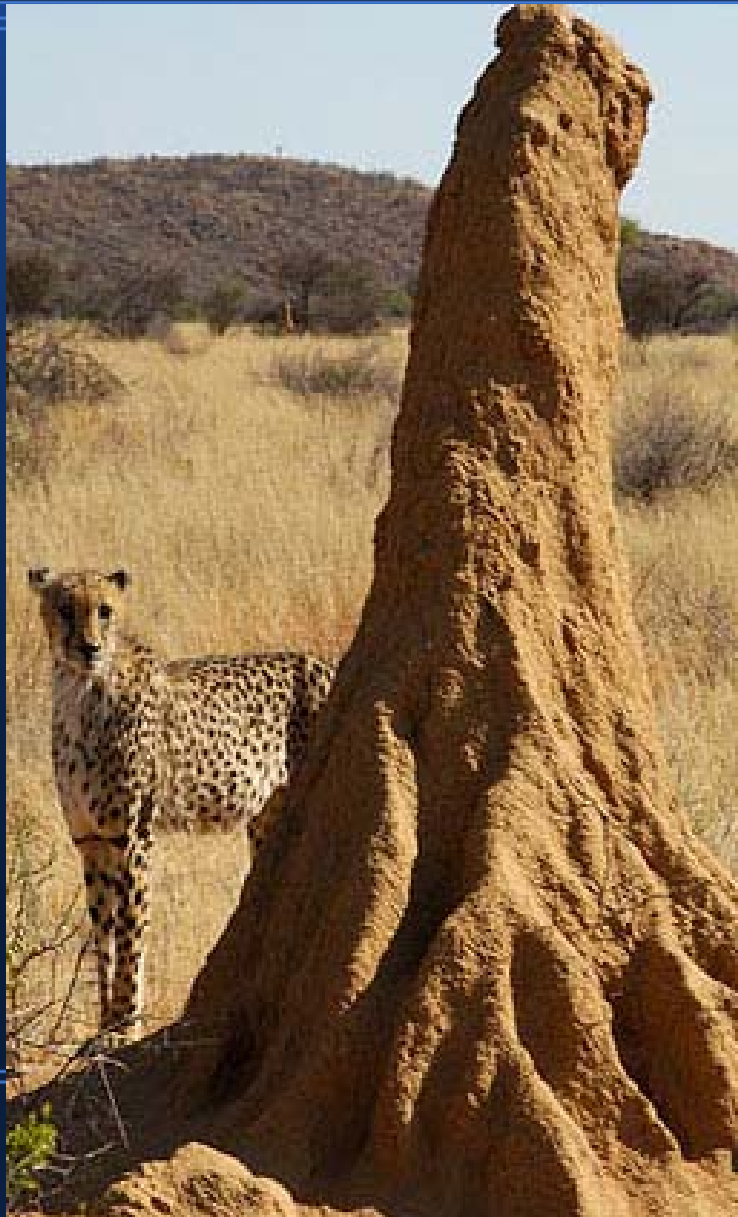
# Biomimetic - Examples

- Computer algorithms, particle swarm, genetic algorithms, neural networks, etc.



# Biomimetic - Examples

- Architecture





# Biomimetic

- Implications – we don't always need to figure out how to do reach a goal in detail, we can leverage the knowledge of natural systems.
- Emergence – the (possibly unintended) complexity that results from simple rules.
- Stigmergy – The interaction between an environment and what acts on that environment , when changes to the environment modify behavior of the actor.
- Can we quantify what we intuitively know... the environment and the actor form a feedback loop that produces results.

# Problem Definition

- We want to go to Mars.
- As people, not only machines.

People need shelter.

Long term manned presence requires a live off the land approach.

In-Situ Resource Utilization (ISRU) is necessary.



# Problem Definition

- ISRU state of the art (Mars)
  - Mars ground is hard and cold
  - Can't just take a shovel to the ground
  - Melting, jackhammer, microwave sublimation, approaches all have pros/cons
  - Techniques exist for extracting water, oxygen, hydrogen, methane, magnesium, CO<sub>2</sub>, etc. Even recipes for martian concrete.
- Environment modeling is important.
  - The environment dynamics encourage the solution.

# Problem Definition

The interaction of the environment with constraints will determine what the best habitat looks like.

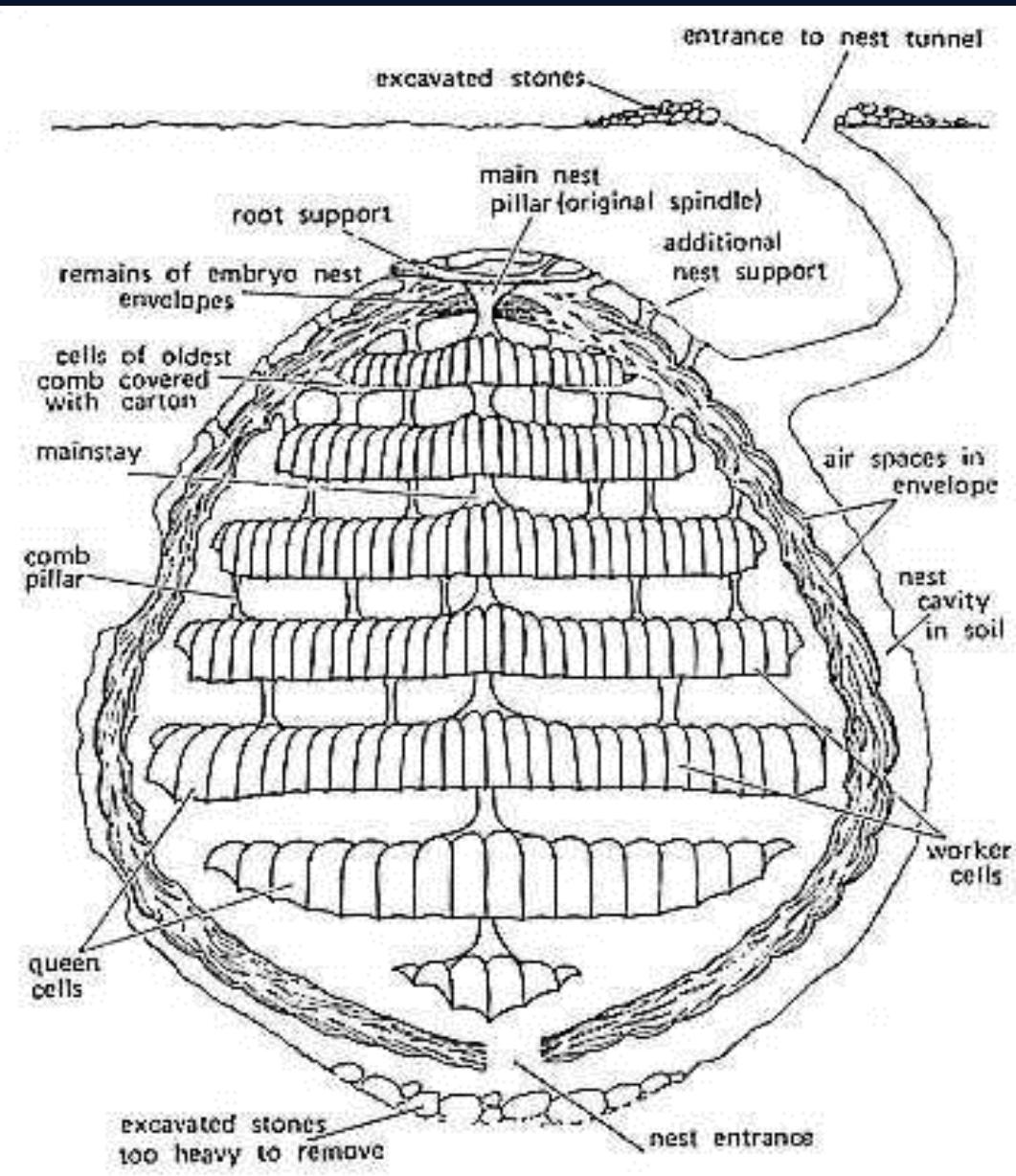
Question:

How can we build a human habitat on another planet when we can't send either a human construction crew or many materials?

An autonomous robotic solution combined with ISRU is an obvious approach, but how?



# Approach – Social Animal Behavior can be leveraged.



- Termites are a good inspiration.
- Global results from purely localized behavior.
- Termites do not have a blueprint to work from.
- Termites are blind and act locally only, can be a simple robot.
- Simple behavior yields unexpected complexity – Emergence.



# Approach

Simple termite rule set...

- In the 1950's, Pierre-Paul Grassé formulated stigmergy, observing simple rules for termite behavior
  - 1. Find dirt & grab
  - 2. Perform random walk until a raised area is found
  - 3. Drop dirt and go back to step one...
  - 4. ...until enough height is reached and then start on arches
  - 5. Keep repeating.
- Biologists now know that in addition there are pheromones involved
  - Produce feedback and behavior amplification/reinforcing

# Approach

## Stigmergy

The behavior of the agents (termites) modifies the environment.

The environment state modifies the behavior of the agents.

Rinse and repeat.

The indirect communication mechanism between the agents passing through the environment is Stigmergy.

Some candidate algorithms

- Particle Swarm Optimization
- Ant/Termite Colony Optimization
- Custom

# Particle Swarm Optimization (PSO)

- A Computational Intelligence (CI) algorithm inspired from animal behavior, flocking & schooling observation.
- Population based approach, a subset of evolutionary computation.
- Exhibits Emergence



# Particle Swarm Optimization (PSO)

- Each particle represents a full solution to the problem that is graded with a cost function.
- The best cost particle attracts other particles.
- An individual particle's past best also attracts.
- The push/pull effect of this behavior efficiently searches the error space for solutions.
- $v_i(k+1) = v_i(k) + \varphi_{1i}(p_i - x_i(k)) + \varphi_{2i}(G - x_i(k))$
- $x_i(k+1) = x_i(k) + v_i(k+1)$

# Ant/Termite Colony Optimization

Inspired by foraging patterns of ants

Real ants communicate by using pheromones.

The ants tend to use shortest route between 2 points.

Problem must be transformed

Finding the best path on weighted graph

The “ants” find solutions by traversing the graph

As the agents (ants) traverse the problem (graph) they leave a pheromone trail.

The ants are attracted to areas with more pheromones, i.e. the most traveled paths.

There is also a random component to the movement, biasing toward unexplored regions.

The balance between being attracted to large pheromone trails and unexplored trails creates the dynamics.

Handles dynamic error topologies.



# Modeling considerations

PSO looks like a great starting point to model termite behavior.

Population based

Physical-like dynamics

Simple memory

Cost function determines behavior

Requires some modification

Cost function will need to modify environment, error space

Global best will not be a particle but a state of the error space

PSO has no analog to pheromones

# Modeling considerations

The concept of pheromones can be added to the basic PSO  
Algorithm is a custom hybrid of PSO and Ant/Termite colony  
optimization.

Combines

Native ability to handle changing environments

Robustness to non-linearity and discontinuities

Population based with a stochastic component

Both short and mid-term memory for each agent

Agent trajectories have realistic dynamics due to position and velocity  
terms

Should be enough to start experimenting

# Modeling considerations

Don't forget the environment!

To trigger emergent behavior wanted requires feedback between environment and agent.

The environment model may consider

Different levels of soil density, pockets, ice, materials

Gravity, clumping, shifting, maybe even electrostatic effects

To examine temperature stability, thermodynamic modeling.

To model capillary action, surface winds must be accounted for.

The environmental model can get very complicated, more so than the agent model.

Can be refined over time.

# Modeling considerations

The candidate agent swarm algorithm has been chosen.

The candidate environmental model has been fleshed out.

What ties agent and environment together is the cost function

The cost function grades the actions on the environment

By convention the best solution is said to minimize the cost function, i.e. a “lowest cost” case.

The cost function is where desired outcome is coded.

# Approach - modeling

Desired outcome

NOT a blueprint!

Think of cost function as a list of constraints

- Even temperature
- Stable walls
- Roomy, smooth, etc.
- Stigmergic, different phases of construction
- Constraints can change over time
- Can be culled from many references on Habitat Construction Requirements.

The end result is not specifically dictated, only the constraints.

It is up to the agents follow the simple rules coded into behavior

- Subject to constraints
- Subject to the environment

Leveraging Emergence – the complexity from simple rules.



# Summary

Nature provides efficient mechanisms for solving difficult engineering problems.

The behavior of social animals is particularly interesting.

Exhibit emergence, very simple rules for the individual yield complex global results through stigmergic (closed loop) effects.

Error tolerant by virtue of many agents working together.

Can't send a team of humans for extraterrestrial construction and impractical to send enough raw materials for habitats.

Low cost (capability) robots can be sent to utilize existing local materials, using existing technology.

Sending lots of robots while applying a termite inspired behavior model, leverages indirect communication based on local input to achieve global problem solution.

The human habitat will grow not based on a blueprint but based on agent behavior, environmental effects, and designer determined and possibly dynamic constraints.

The approach outlined has implications not only for extra-terrestrial habitation, but Earth based problems as well.

# References & Further Reading

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